MILK-ENERGY FORMULAS FOR VARIOUS BREEDS OF CATTLE [1]

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INTRODUCTION

The calorific value of milk is important as a measure of the human food value of the milk, the amount of feed required by the cow for lactation, and as a measure of lactation for the study of inheritance of milking ability.

Direct determination of the calorific value of milk has not been carried out very extensively. Overman and Sanmann (*8*, *9*) [2] have reported analyses, including energy, of 212 samples without classifying them as to the breed of cow. Similar data have been reported by Möllgaard (*7*) on 60 samples from Red Danish cows and 11 samples from Jersey cows; by Kahlenberg and Voris (*6*) on 134 samples from Holstein cows; and by Savini and Gargia (*11*) on about 100 samples of market milk collected in the retail trade. All these investigators have pointed out the possibility of estimating the energy value of milk from its fat percentage. Overman and Sanmann found the correlation between fat percentage and calories per kilogram of milk to be $r=0.9814 \pm 0.0017$.[3] That is to say, the energy content of the whole milk produced by the cow may be estimated with a high degree of accuracy from its weight and fat percentage. The equations are given in Table 3.

Kahlenberg and Voris derived the formula, $E=183f-56.73t+556.32$, where E is calories per kilogram of milk, f is the percentage of fat and t is the percentage of solids not fat. According to this equation, at a given fat percentage increasing the solids not fat decreases the energy value, which does not seem reasonable. Also, inspection of their data suggests that the cofficient of t should be positive. For example, there are four observations at $f=3.76$ and within these four we find:

Percentage of solids not fat	7. 68	8. 69	8. 92	8. 95
Calories per kilogram of milk, determined	667	705	710	720

In this particular instance, at least, energy tends to increase with the solids not fat.

The writers have taken the trouble to recompute the formula from the published analyses, without coding, by use of the method described by Brandt (*2*). The results are $R_{E.ft}=0.9930$, and $E=93.68f+44.55t-34.09$. In this equation the coefficients of f and t are both positive and substantially in the ratio of the average energy values of fat and solids not fat, while the constant factor is very small as compared with

[1] Received for publication Jan. 4, 1933; issued July, 1933.
[2] Reference is made by number (italic) to Literature Cited, p. 1120.
[3] This value was computed by coding. Use of their published data without coding gives $r=0.9874$, a substantially higher value. When dealing with such highly correlated variables it is desirable to use small class intervals.

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that of Kahlenberg and Voris. By using the above example again, results from the two formulas in comparison with the determined energy values are:

Kahlenberg and Voris formula	809	751	738	737
Determined	667	705	710	720
Present formula	660	705	716	717

Clearly the present formula agrees with the observations much better than does the formula of Kahlenberg and Voris.

While the data of Overman and Sanmann were not classified as to breed directly, the fat-percentage classification itself would automatically make some breed separation. The plotted values showing the regression of energy on fat percentage seem to be entirely linear, with no evidence of any breed influence. On the other hand, the equations of Möllgaard and Kahlenberg and Voris suggest that there may be breed differences of some significance with respect to the relation between energy and fat percentage. What is needed is an extension of these direct determinations to a larger number of samples and especially to a larger population of cows in each of the several breeds. However, it seems worth while as a preliminary to a study of breed differences to see what information may be gained from the analyses of milk of the different breeds. Such information may have value also in itself.

In the present paper certain analyses from this laboratory are presented, and a comparison is made between the different breeds with respect to milk energy. The analyses used are the 212 reported by Overman and Sanmann (*8, 9*) which include direct energy determinations, and another set of 1,999 by Overman, Sanmann, and Wright (*10*), classified by the breed of cow, and similar to the 212 except that they do not include direct energy determinations. The energy of the milk components was derived from the 212 analyses, and these component values were than applied to the 1,999 analyses in order to derive the milk energy.

ENERGY OF MILK COMPONENTS

The energy of milk obviously lies in its several components. If both the milk energy and the amounts of the several milk components are known for a series of observations, it should be possible to deduce the energy factor for each component. It should then be permissible to apply these factors to other analyses in which energy was not determined and thereby estimate the milk energy.

It may be assumed that all of the 212 analyses including energy are equally reliable and that such discrepancies as may exist among them with respect to the present point of view are due to errors or differences of a random nature; then it may be assumed that the most probable energy values of the several components may be determined by applying the principle of least squares to the whole series of observed values. For illustration, if the energy of milk resided entirely in the fat, protein, and lactose and absolutely accurate determinations of these items in three divergent samples of milk were available, as well as the accompanying milk energy, then it would be merely necessary to set up the results as three equations and solve for the energy value of fat, protein, and lactose. It is clearly not justifiable to pick 3 out of the 212 to be used in preference to any other 3. The theoretically correct procedure is to form a set of normal equations from the 212 observations and thus arrive at the proper values from all the observations. This procedure has been followed, by using the method described by Brunt (*3*) and assuming that the energy resides in (1) fat, protein, and lactose; (2) fat, protein, lactose, and ash; and (3) fat, protein, lactose, ash, and water. The results are presented in Table 1.

TABLE 1.—*Energy value of milk components in calories per gram*

Component	Values based on energy residing in—			Standard values reported by Abderhalden
	Fat, protein, lactose, ash, and water	Fat, protein, lactose, and ash	Fat, protein, and lactose	
Fat	9.312	9.434	9.253±0.065	9.23
Protein	5.358	5.161	5.853± .127	5.71
Lactose	3.987	3.480	3.693± .059	3.95
Ash	4.980±0.199	4.323±0.173		
Water	−.0356± .0059			

Table 1 shows that the values found for fat, protein, and lactose fluctuate to some extent according to the components considered in calculating the values. This suggests that the method is not adapted to the exact estimation of the energy of milk components. The standard values for fat, protein, and lactose directly determined, as given by Abderhalden (*1*), are given in the last column. The present indirectly determined values, based on fat, protein, and lactose, agree very closely with the standard values in the case of fat but poorly in the case of lactose. Lactose was determined by difference, and the poor agreement perhaps means that the errors of determination thus tend to concentrate in this portion. The good agreement of the fat values, on the other hand, may reflect a superior accuracy in the fat determination, along with the high proportion of the total milk energy represented by the fat.

It might be concluded in advance that the water has no energy value and should be left out of consideration. Statistically the value found is significant although absolutely so small that the result may be regarded as a favorable comment on the consistency of the analyses. Likewise, the ash might have been ruled out in advance as having no appreciable energy value. On analysis, the value found, while appreciable per gram, becomes of little consequence when considered in connection with the small quantity of ash present in the milk.

The question now arises as to which set of values in Table 1 may best be used in estimating milk energy from the chemical analyses. A prior one might conclude that water should certainly be excluded, and probably ash also, fat, protein, and lactose being chosen as the most rational set. We are concerned, however, in making the most accurate estimate we can of the milk energy from the milk analyses. It is not at all inconceivable that, while there is no "negative energy" to be attributed to the water of the milk as analyzed, there may nevertheless be some peculiarity associated with high-water milk which tends to make the energy determination run slightly lower. Similar reasoning may be applied to the ash. Since the analyses, without energy, which it is proposed to use, are entirely comparable with those involved in Table 1, it seems clear that statistically the best energy estimate will be obtained by the use of all five components—that is, $E=93.12f+53.58p+39.87l+49.80a-0.356w$, where E is calories per kilogram of milk and f, p, l, a, and w are the percentages of fat, protein, lactose, ash, and water, respectively.

BREED FORMULAS

The above formula has been applied to the milk analyses, classified by breed, as published by Overman, Sanmann, and Wright (*10*). The analyses for each breed were grouped by fat percentage into classes, 2.60–2.79, 2.80–2.99, 3.00–3.19, etc., and the average of the analyses of each group determined. The formula was then applied to these averages to derive the energy values. The results are given in Table 2.

TABLE 2.—*Computed energy values and protein-energy ratios of milk from cows of various breeds and from crossbred cows, grouped by fat-percentage classes*

AYRSHIRE COWS

Fat-percentage class	Records	Fat	Protein	Lactose	Ash	Water	Energy per kilogram of milk	Protein per calorie
	Number	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Calories*	*Milli-grams*
2.80 to 2.99	2	2.920	3.020	4.625	0.658	88.78	619.3	49.0
3.00 to 3.19	3	3.113	3.170	4.607	.694	88.42	646.5	49.0
3.20 to 3.39	12	3.327	3.321	4.553	.679	88.12	671.7	49.5
3.40 to 3.59	12	3.506	3.314	4.689	.655	87.84	692.3	47.9
3.60 to 3.79	27	3.706	3.325	4.673	.659	87.64	711.2	46.8
3.80 to 3.99	24	3.900	3.519	4.551	.688	87.34	736.3	47.8
4.00 to 4.19	34	4.085	3.635	4.772	.684	86.82	768.6	47.3
4.20 to 4.39	34	4.292	3.576	4.609	.686	86.85	778.3	45.9
4.40 to 4.59	20	4.498	3.720	4.821	.691	86.27	814.1	45.7
4.60 to 4.79	19	4.691	3.802	4.708	.695	86.10	832.2	45.7
4.80 to 4.99	7	4.863	3.794	4.683	.702	85.96	847.2	44.8
5.00 to 5.19	5	5.112	3.888	4.948	.703	85.35	886.3	43.9
5.20 to 5.39	5	5.314	3.976	5.026	.707	84.98	913.2	43.5
5.40 to 5.59	3	5.490	4.140	5.007	.753	84.61	940.1	44.0
5.60 to 5.79	1	5.66	4.38	4.80	.730	84.43	959.4	45.7

GUERNSEY COWS

Fat-percentage class	Records	Fat	Protein	Lactose	Ash	Water	Energy per kilogram of milk	Protein per calorie
3.60 to 3.79	3	3.720	3.727	4.963	0.702	86.89	748.0	49.8
3.80 to 3.99	7	3.914	3.360	4.684	.701	87.34	735.1	45.7
4.00 to 4.19	10	4.078	3.561	4.995	.728	86.64	775.1	45.9
4.20 to 4.39	15	4.297	3.661	4.853	.735	86.45	795.6	46.0
4.40 to 4.59	29	4.499	3.663	4.965	.717	86.15	818.2	44.8
4.60 to 4.79	38	4.689	3.757	4.958	.716	85.88	840.7	44.7
4.80 to 4.99	36	4.894	3.907	4.978	.733	85.49	869.6	44.9
5.00 to 5.19	39	5.149	3.992	4.958	.737	85.21	897.4	44.5
5.20 to 5.39	35	5.274	4.015	4.924	.745	85.05	909.4	44.1
5.40 to 5.59	24	5.485	4.199	4.927	.761	84.63	940.0	44.7
5.60 to 5.79	22	5.693	4.165	4.921	.757	84.46	957.1	43.5
5.80 to 5.99	19	5.897	4.253	4.922	.753	84.17	980.8	43.4
6.00 to 6.19	12	6.068	4.612	4.711	.770	83.78	1,008.5	45.6
6.20 to 6.39	11	6.285	4.555	4.761	.773	83.62	1,027.9	44.3
6.40 to 6.59	9	6,472	4.611	4.754	.804	83.36	1,049.6	43.9
6.60 to 6.79	5	6.662	4.770	4.740	.788	83.04	1,074.6	44.4
6.80 to 6.99	3	6.877	4.847	4.743	.829	82.70	1,101.0	44.0
7.00 to 7.19	1	7.06	4.98	4.78	.768	82.41	1,123.7	44.3
7.20 to 7.39	1	7.37	4.70	4.88	.816	82.23	1,144.0	41.1
7.60 to 7.79	2	7.650	4.790	4.605	.812	82.14	1,163.8	41.2

TABLE 2.—*Computed energy values and protein-energy ratios of milk from cows of various breeds and from crossbred cows, grouped by fat-percentage classes*—Continued

HOLSTEIN COWS

Fat-percentage class	Records	Fat	Protein	Lactose	Ash	Water	Energy per kilogram of milk	Protein per calorie
	Number	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Calories*	*Milli-grams*
2.60 to 2.79	8	2.709	3.055	5.000	0.656	88.58	616.4	49.6
2.80 to 2.99	25	2.890	3.012	4.928	.666	88.51	628.6	47.9
3.00 to 3.19	40	3.104	3.169	4.846	.672	88.21	654.1	48.4
3.20 to 3.39	47	3.289	3.276	4.884	.671	87.88	678.6	48.3
3.40 to 3.59	42	3.488	3.388	4.853	.688	87.58	702.9	48.2
3.60 to 3.79	35	3.674	3.361	4.866	.672	87.43	718.5	46.8
3.80 to 3.99	29	3.874	3.502	4.863	.681	87.08	745.2	47.0
4.00 to 4.19	11	4.078	3.734	4.858	.694	86.64	777.2	48.0
4.20 to 4.39	13	4.313	3.967	4.722	.697	86.30	806.4	49.2
4.40 to 4.59	5	4.510	4.240	4.998	.736	85.51	852.6	49.7
4.60 to 4.79	4	4.700	4.075	4.757	.692	85.77	849.6	48.0
5.00 to 5.19	3	5.156	4.586	4.730	.735	84.79	920.8	49.8
5.20 to 5.39	3	5.306	5.010	4.833	.804	84.05	965.3	51.9
5.60 to 5.79	2	5.680	5.420	4.490	.812	83.60	1,009.0	53.7
6.00 to 6.19	1	6.00	4.88	4.66	.794	83.67	1,015.7	48.0

JERSEY COWS

Fat-percentage class	Records	Fat	Protein	Lactose	Ash	Water	Energy per kilogram of milk	Protein per calorie
3.20 to 3.39	1	3.280	3.22	3.67	0.789	89.04	631.9	51.0
3.60 to 3.79	5	3.680	3.896	3.942	.729	87.75	713.7	54.6
3.80 to 3.99	8	3.910	3.623	4.860	.683	86.92	755.1	48.0
4.00 to 4.19	5	4.074	3.302	4.866	.660	87.10	752.2	43.9
4.20 to 4.39	11	4.292	3.695	5.126	.697	86.19	806.1	45.8
4.40 to 4.59	18	4.493	3.648	5.058	.691	86.11	819.3	44.5
4.60 to 4.79	16	4.668	3.556	5.059	.681	86.03	830.2	42.8
4.80 to 4.99	20	4.881	3.715	5.058	.693	85.65	859.3	43.2
5.00 to 5.19	19	5.091	3.896	4.919	.694	85.40	883.1	44.1
5.20 to 5.39	26	5.295	3.859	5.026	.698	85.12	904.7	42.7
5.40 to 5.59	16	5.479	3.891	4.986	.693	84.95	921.7	42.2
5.60 to 5.79	16	5.707	4.171	4.963	.743	84.42	959.7	43.5
6.80 to 5.99	12	5.892	4.288	4.929	.732	84.16	981.4	43.7
6.00 to 6.19	8	6.081	4.264	4.764	.726	84.17	990.9	43.0
6.20 to 6.39	5	6.230	4.010	4.982	.713	84.06	999.2	40.1
6.40 to 6.59	4	6.445	4.068	4.788	.727	83.97	1,015.3	40.1
7.60 to 6.79	5	6.666	4.008	5.042	.709	83.58	1,042.1	38.5
7.80 to 6.99	1	6.80	4.44	4.96	.698	83.10	1,074.0	41.3
8.20 to 7.39	1	7.34	4.91	4.06	.650	83.04	1,111.3	44.2
5.40 to 7.59	1	7.59	3.23	5.15	.706	83.32	1,090.7	29.6
8.20 to 8.39	2	8.365	4.925	3.605	.772	82.33	1,195.7	41.2

CROSSBRED COWS

Fat-percentage class	Records	Fat	Protein	Lactose	Ash	Water	Energy per kilogram of milk	Protein per calorie
2.60 to 2.79	1	2.72	3.27	3.91	0.682	89.42	586.5	55.8
2.80 to 2.99	4	2.933	2.915	5.113	.682	88.36	635.7	45.9
3.00 to 3.19	19	3.085	3.103	5.093	.689	88.03	659.6	47.0
3.20 to 3.39	19	3.295	3.203	5.048	.685	87.77	682.6	46.9
3.40 to 3.59	61	3.497	3.466	4.987	.697	87.35	713.8	48.6
3.60 to 3.79	89	3.700	3.514	4.929	.711	87.15	733.7	47.9
3.80 to 3.99	111	3.895	3.560	4.917	.716	86.91	754.2	47.2
4.00 to 4.19	125	4.099	3.622	4.878	.723	86.68	775.4	46.7
4.20 to 4.39	110	4.293	3.790	4.894	.723	86.30	803.2	47.2
4.40 to 4.59	130	4.489	3.864	4.820	.723	86.10	822.6	47.0
4.60 to 4.79	93	4.690	3.918	4.833	.739	85.82	845.6	46.3
4.80 to 4.99	70	4.895	4.046	4.820	.737	85.50	871.0	46.5
5.00 to 5.19	60	5.090	4.149	4.834	.743	85.18	895.7	46.3
5.20 to 5.39	42	5.278	4.275	4.665	.739	85.04	913.1	46.8
5.40 to 5.59	27	5.477	4.480	4.818	.761	84.46	950.0	47.2
5.60 to 5.79	17	5.679	4.422	4.558	.769	84.57	955.7	46.3
5.80 to 5.99	11	5.874	4.735	4.383	.756	84.25	983.1	48.2
6.00 to 6.19	2	6.120	4.835	4.640	.776	83.63	1,022.8	47.3
6.20 to 6.39	4	6.290	4.655	4.658	.769	83.63	1,029.4	45.2
6.40 to 6.59	6	6.472	4.653	4.747	.798	83.33	1,051.3	44.3
7.40 to 7.59	1	7.50	5.54	4.04	.814	82.11	1,167.6	47.4

The equation $E = a + bf$ has been fitted to the average fat-percentage and energy values of each of these tables by the method of least squares, and weighting by the number of records at each fat-percentage class. The equations are given in Table 3, together with the directly determined equations of the investigators referred to at the outset.

TABLE 3.—*Milk-energy formulas for various breeds of cows*

Breed	Formula [a]	Authority
Not classified	$E=115.33\ (2.51+f)$	Overman and Sanmann.
Red Danish	$E=115\ (2.44+f)$	Möllgaard.
Jersey	$E=101\ (3.59+f)$	Do.
Holstein	$E=128.55\ (1.89+f)$	Kahlenberg and Voris.
Jersey	$E=106.98\ (3.15+f)$	Present paper.
Holstein	$E=128.19\ (1.99+f)$	Do.
Guernsey	$E=116.80\ (2.52+f)$	Do.
Ayrshire	$E=121.00\ (2.20+f)$	Do.
Crossbred	$E=116.11\ (2.61+f)$	Do.

[a] E=calories per kilogram milk, f=percentage fat content of milk.

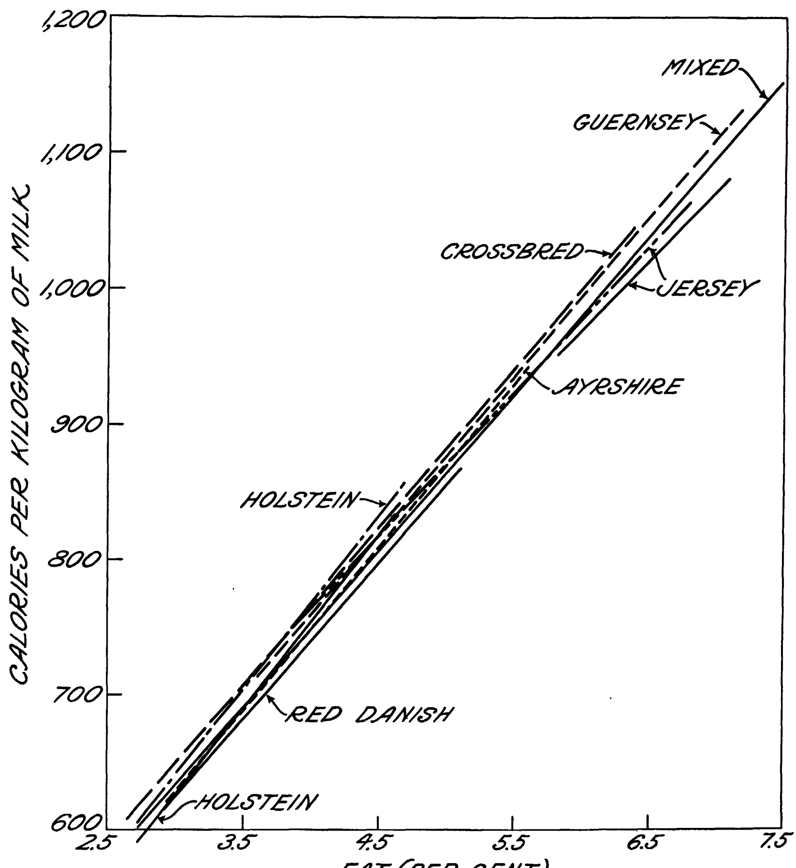

FIGURE 1.—Fitted curves showing relation of milk energy to fat percentage. The broken lines represent data of this paper. Equations in Table 3

A study of this table suggests that there is undoubtedly some difference in the slopes of the breed curves. The Holstein breed has the steepest curve and the Jersey breed the flattest. The slope of the present indirectly determined curve for the Holstein breed agrees very closely with the directly determined data of Kahlenberg and Voris. The similar comparison with Möllgaard's Jersey data shows somewhat less exact agreement, but the results are in accord in indicating a difference between the two breeds.

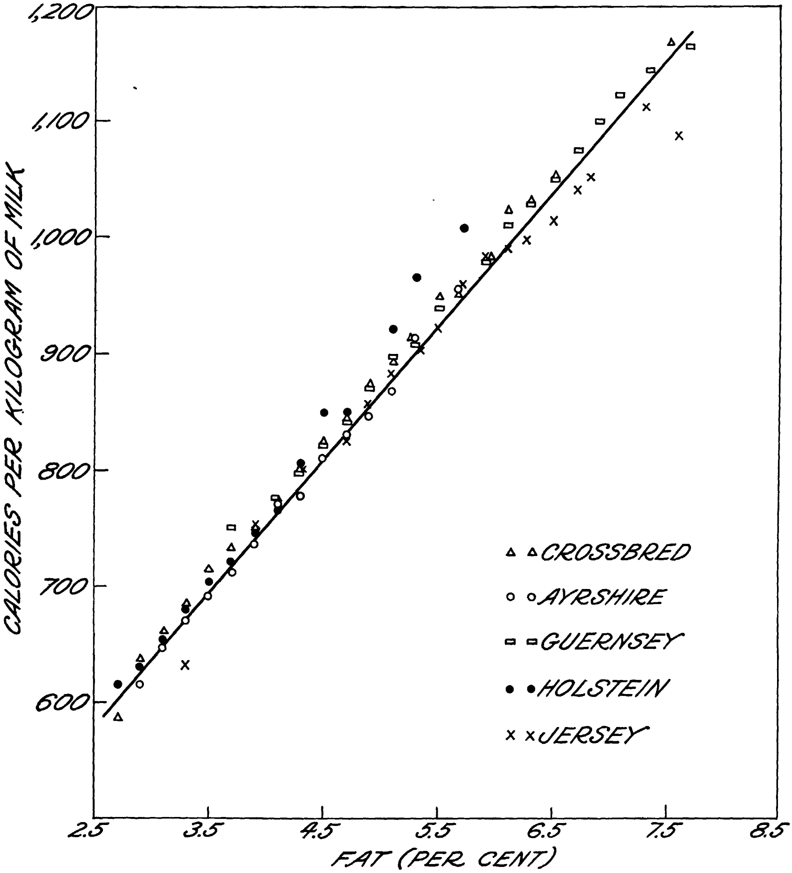

FIGURE 2.—Observations of Table 2 showing relation of milk energy to fat percentage. The line represents Overman and Sanmann's equation

The curves of the equations of Table 3 are plotted in Figure 1, which gives a better general view of the variation between breeds than do the equations. The curves are plotted to cover the range of fat percentage found in the observed data on which they are based. Considered within these limits the curves all lie in a comparatively narrow band with slope practically the same as that of Overman and Sanmann's mixed data. While the difference in breeds may be of real significance, there is no great error involved, within the usual fat-percentage range of any breed, by using a single equation to describe the fat-energy relation for all breeds.

The computed energy values of Table 2 are plotted against fat percentage in Figure 2. The curve of Overman and Sanmann's equation is also given as a guide. It is apparent that a majority of the observations lie above this line—that is, the equation gives values slightly too low to fit the observed values. This figure brings out a difference between high-testing Holstein and Jersey samples. High-testing Holstein samples tend to show an energy content above that expected, while the high-testing Jersey samples tend to show an energy content below that expected. In general, Figure 2 shows that breed differences are slight for samples testing within the usual fat-percentage range of the breed.

PROTEIN-ENERGY RATIO

Fredericksen (*4*) has pointed out that the ratio of protein to energy is nearly the same regardless of the natural fat-content percentage of the milk. This observation is of prime importance from the point of view of the whole-milk trade and from the point of view of dairy feeding standards. The protein-energy ratio has been computed for each fat-percentage class and is given in the last column of Table 2. The ratios for each breed have been connected with the fat percentage by means of the equations given in the following tabulation. The equations were fitted by the method of least squares weighting by the frequencies.

Breed	Milligrams of protein per calorie	Breed	Milligrams of protein per calorie
Holstein	$46.49+0.46f$	Ayrshire	$56.29-2.32f$
Crossbred	$49.68-.61f$	Jersey	$55.59-2.32f$
Guernsey	$48.89-.83f$	Jersey [4]	$47.93-.87f$

The observed ratios and fitted curves are shown graphically in Figures 3 and 4, and all the fitted curves are brought together in Figure 5. There seem to be marked differences between the breeds in the change of the protein-energy ratio with change in fat percentage. The Holstein breed shows a general tendency for the ratio to increase with increase of fat percentage, while the Ayrshire breed shows a marked decrease in the proportion of protein to energy as the fat percentage increases. It seems safe to say that the Ayrshire and Holstein breeds are significantly different in the protein-energy ratio of their milk. It may be noted that the Holstein observed values (fig. 3) are somewhat irregular, while the Ayrshire values (fig. 4) conform very closely to the fitted curve throughout the range.

According to the fitted curves as shown in Figure 5, the Ayrshire and Jersey breeds resemble each other and stand more or less apart from the other breeds. Reference to Figure 4 suggests, however, that the Jersey curve may be influenced to a considerable degree by the observations below $f=4.10$, and above $f=6.10$. If these observations, representing 33 analyses or 16.5 per cent of the total, are excluded a much flatter curve is obtained, as shown by the broken line in Figures 4 and 5. This limited Jersey curve resembles the Guernsey curve. The data therefore leave one in doubt as to the genuineness of the resemblance of the Jersey curve to the Ayrshire

[4] For limits of $f=4$ to $f=6.19$.

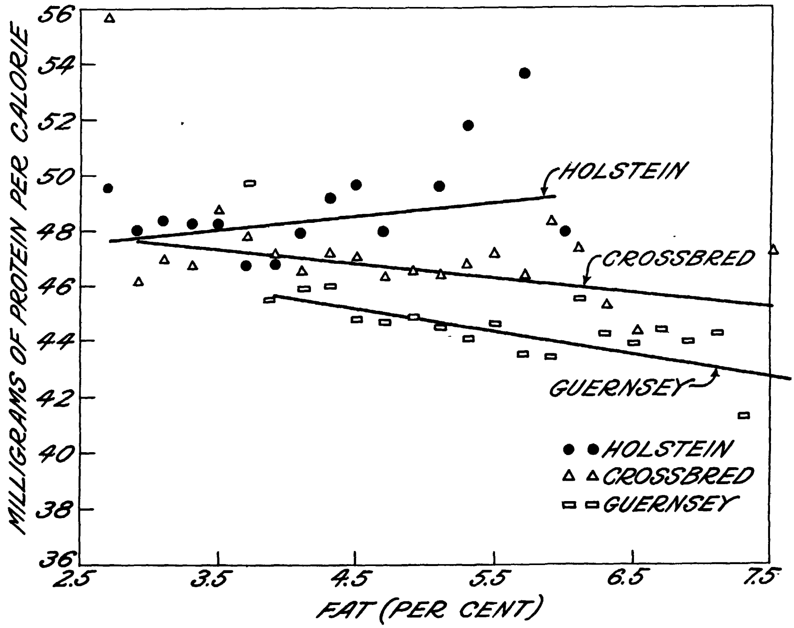

FIGURE 3.—Relation between the protein-energy ratio and the fat percentage of the milk from Guernsey and Holstein breeds and crosses of these two breeds. The lines represent the fitted equations

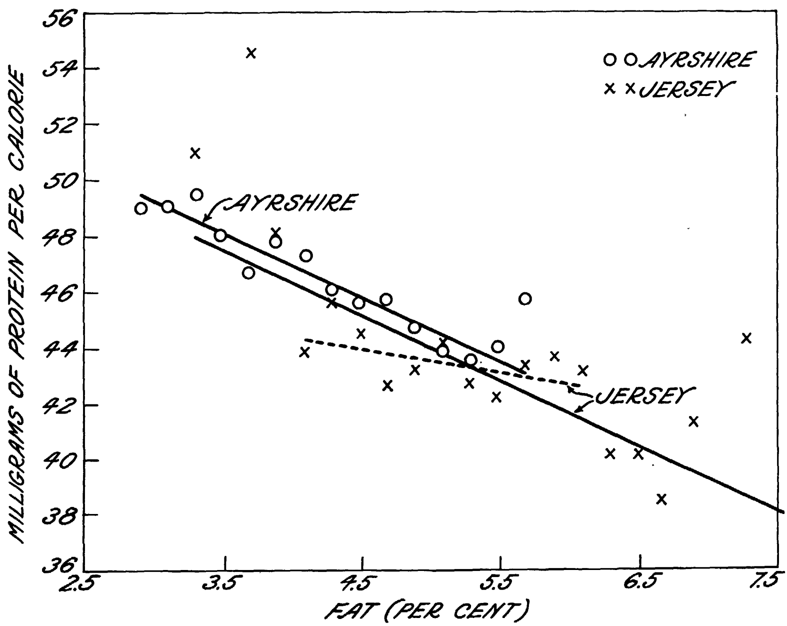

FIGURE 4.—Relation between the protein-energy ratio and the fat percentage of the milk from Ayrshire and Jersey breeds. The solid lines represent the fitted equations; the broken line applies to the Jersey data over the limited fat-percentage range

curve. It would be more natural on the basis of ancestral descent to accept the resemblance to the Guernsey curve.

Generally speaking, the present ratios indicate that the amount of protein in whole-milk samples from cows of all breeds lies between 43 and 49 mg of protein per calorie. If we were to deal with the lactation milk yield of individual cows, or mixed herd milk, this range would undoubtedly be considerably reduced. So far as the whole-milk trade is concerned it is apparent that the reduction of normal whole milk to a calorie basis places it on a food basis not only with respect to total nutrients, but also, substantially, with

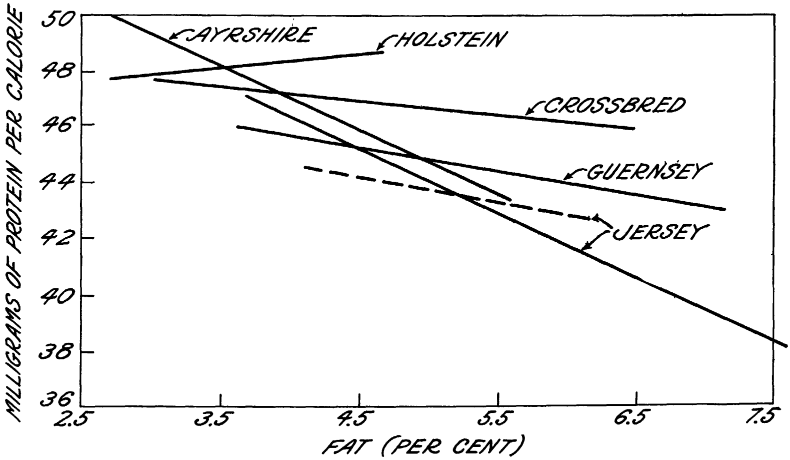

FIGURE 5.—Fitted curves showing the relation between the protein-energy ratio and the fat percentage of milk from different breeds of cattle. The broken line applies to the Jersey data over the limited fat-percentage range. The equations are given in the text

respect to its protein content. So far as feeding standards for milk cows are concerned, it is apparent that on a calorie basis the variation in protein content of the milk is practically negligible.

SIMPLIFIED DAIRY FEEDING STANDARD

The feed requirements for milk production are generally given in table form, listing numerous fat-percentage classes of milk. It has been shown (*5, fig. 4*) that the total nutrients required for lactation are closely proportional to the milk energy (Haecker's law). Since the milk protein is also substantially proportional to milk energy, it follows that the main food requirements, total digestible nutrients, and protein can be expressed as very simple functions of the milk energy.

One way of expressing milk energy is in terms of 4 per cent milk by the formula, 4 per cent milk $=0.4M+15F$, where M is milk and F is fat, all in the same unit of weight. On the basis of 750 calories per kilogram of 4 per cent milk this formula is practically the same as that of Overman and Sanmann. Figure 1 shows that this formula is an adequate expression for all the breeds from a practical standpoint. One kilogram of 4 per cent milk, natural or by the $0.4M+15F$ formula, contains 750 calories and 37 g of protein, on the basis of 50 mg of protein per calorie. Allowing a 100 per cent margin for calories and a 50 per cent margin for protein (in line with current feeding standards), the lactation requirement for 1 kg of 4 per cent milk would be, therefore, 1,500 calories of digestible feed energy and 55 g of digestible protein. This principle is embodied in a plan for the teaching and practice of feeding dairy cows which is widely used in the Scandinavian countries at the present time.

So far as dairy cows alone are concerned, it would appear entirely sufficient to determine for the various feeding stuffs simply the content of energy and protein and the digestibility coefficient for these two items. The feeding value might then be expressed in terms of digestible energy and digestible protein, which as above pointed out, bear a definite ratio to the 4 per cent milk requirements. This would reduce the amount of work necessary in feed analyses and digestion trials.

INHERITANCE ASPECTS

From an inheritance point of view it is interesting to compare the curves of Figures 1 and 5 relating to cows of the Guernsey and Holstein breeds and the crossbred cows resulting from the crossing of these two. With regard to the relation of milk energy to fat percentage the difference between the parental breed curves is not great, and there is consequently little chance for clear-cut results in the cross. The slope of the crossbred curve is the same as that of the Guernsey breed and somewhat less than that of the Holstein breed.

In the case of the protein-energy ratio, however, there is more difference in the parental breeds, and the crossbred cows take more or less distinctly an intermediate position. (Fig. 3.) It should be mentioned that the Guernsey and Holstein samples are not from the actual parents of the crossbred cows, but only from cows of the same breed as the parents.

SUMMARY

Milk-energy formulas for the Ayrshire, Guernsey, Holstein, and Jersey breeds, and Guernsey-Holstein crossbred cows have been derived from analyses available from this laboratory. The analyses (212), including a direct energy determination, were used to determine the energy value of the several milk components. The values were then applied to another, more extensive series of analyses (1,999), and the milk energy was thus indirectly determined. Based on fat, protein, and lactose only, the following values in calories per gram were found: Fat, 9.253 ± 0.065; protein, 5.853 ± 0.127; lactose, 3.693 ± 0.059.

The breed formulas for the estimation of milk energy based on the fat percentage showed small but probably significant differences. As compared with the original formula of Overman and Sanmann the breed formulas, considered within the usual fat-percentage limits, all lay within a narrow band on either side. It is concluded that for practical purposes it is permissible to use a single formula for all breeds, which may be expressed in terms of 4 per cent milk as 4 per cent milk $= 0.4M + 15F$, in which M is the weight of milk and F is the weight of fat, all in the same unit. One kilogram of 4 per cent milk = 750 calories, or perhaps slightly more.

The change in the protein-energy ratio with change in fat percentage showed more marked breed differences than were found for milk energy. Crossbred cows were intermediate as compared with the parent breeds. In a rough way the protein-energy ratio may be considered constant, lying usually within the limits of 43 to 49 mg. of protein per calorie. With respect to protein and energy content the human food value of natural cows' milk is therefore proportional to the amount of 4 per cent milk by the above formula. For the purpose of a usable feeding standard for milk production, the milk may be converted to a 4 per cent basis by the above energy formula and the digestible energy and protein requirements then expressed as constant multiples of the 4 per cent milk. It is suggested that feeding standards for milk production might be adequately handled by determining only the energy and protein in the feed, together with their digestion coefficients.

LITERATURE CITED

(1) ABDERHALDEN, E.
1908. TEXT-BOOK OF PHYSIOLOGICAL CHEMISTRY IN THIRTY LECTURES. Transl. by W. T. Hall and G. Defren. 722 p. New York.

(2) BRANDT, A. E.
1928. THE USE OF MACHINE FACTORING IN MULTIPLE CORRELATION. Jour. Amer. Stat. Assoc. 23:291–295.

(3) BRUNT, D.
1923. THE COMBINATION OF OBSERVATIONS. 219 p., illus. Cambridge.

(4) FREDERICKSEN, L.
1925. FORELØBIGE OPLYSNINGER OM NOGLE FORSØG MED MALKEKØER I VINTEREN 1923–1924. Meddel. K. Vet. og Landbohøjskoles Forsøgslab Husdyrbrug. [Denmark] 2.

(5) GAINES, W. L.
1928. THE ENERGY BASIS OF MEASURING MILK YIELD IN DAIRY COWS. Ill. Agr. Expt. Sta. Bul. 308, p. 403–438, illus.

(6) KAHLENBERG, O. J., and VORIS, LER.
1931. THE PERCENTAGE OF FAT AS A BASIS FOR ESTIMATING THE COMPOSITION OF MILK. Jour. Agr. Research 43:749–755.

(7) MÖLLGAARD, H.
1929. FÜTTERUNGSLEHRE DER MILCHVIEHE. DIE QUANTITATIVE STOFFWECHSELMESSUNG UND IHRE BISHERIGEN RESULTATE BEIM MILCHVIEH. 246 p., illus. Hannover.

(8) OVERMAN, O. R., and SANMANN, F. P.
1926. THE ENERGY VALUE OF MILK AS RELATED TO COMPOSITION. FORMULAS FOR THE COMPUTATION OF THE ENERGY. Ill. Agr. Expt. Sta. Bul. 282, p. 207–218, illus.

(9) ——— and SANMANN, F. P.
1927. VALEUR DU LAIT EN CALORIES. Lait 7:149–161, illus.

(10) ——— SANMANN, F. P., and WRIGHT, K. E.
1929. STUDIES OF THE COMPOSITION OF MILK. Ill. Agr. Expt. Sta. Bul. 325, p. 51–174, illus.

(11) SAVINI, E. and GARGIA, O.
1928. THE DIRECT AND INDIRECT DETERMINATION OF THE ENERGY POWER OF MILK IN RELATION TO THE NUTRITIVE NEEDS OF THE CHILD. World's Dairy Cong., London, Proc. 1928:543–548.